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ALTERNATE APPROACHES FOR RETURNING SEISMIC DATA FROM WITHIN THE WORLD-WIDE SEISMOLOGICAL NETWORK TO SDAC

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Communications Satellite Corporation

Prepared for:

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This report presents recommended system configurations for returning seismic data from seismological research stations in Norway (NORSAR), Iran, and Korea to the Seismic Data Analysis Center (SDAC) in Alexandria, Va. The data are to be returned through INTELSAT earth stations in Sweden, Iran, Korea, and U.S., via INTELSAT satellites located over the Atlantic and Pacific Oceans. Three system approaches were considered, viz, -over

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(1) use of terrestrial microwave systems from the seismic station to the INTELSAT earth station, and subsequent transmission to the satellite on a standard FM carrier; (2) construction of a non-standard earth station at the seismic site for direct access to the satellite using single channel per carrier (SCPC) or SPADE transmission techniques; and (3) the possible use of packet-switching technology by extending the ARPANET to those countries where the seismic sites are located.

Other transmission techniques are discussed, which include FDM/FM/FDMA, SCPC, time sharing of a single satellite channel by two or more earth stations, packet-switching, and other types of data service. If the tariffs to be charged for the services are available, they are also presented.

FINAL REPORT

Alternate Approaches for Returning Seismic Data from Within the Worldwide Seismological Network to SDAC

April 1, 1974

Final Report Submitted to the
Advanced Research Projects Agency

Contract No. F44620-73-C-0025

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ii

Table of Contents

Table of Contents (Continued)

List of Illustrations

List of Tables

1. INTRODUCTION

This report summarizes the work performed during 1973 by the Communications Satellite Corporation (COMSAT) for the Advanced Research Projects Agency (ARPA) under contract F44620-73-C-0024. The purpose of the contract was to determine the optimum method of returning seismic data via satellite from a number of seismological research stations located throughout the world to the Seismic Data Analysis Center (SDAC) in Alexandria, Virginia. Although a number of sites were visited by COMSAT personnel, only those sites which ARPA considers to be of primary importance will be described here. These include sites at Norway (NORSAR), Iran, and Korea. Sites which were to be included in this survey, but which were not visited due to circumstances beyond the control of ARPA and COMSAT, or which were deleted altogether, included Bolivia, Australia, Site II, Japan, and Adac. Should these sites be visited at a later date, a supplemental report will be prepared and issued. The other sites visited but not reported on here include those in Spain, Israel, and Hawaii (U.S.).

The amount of data to be returned to SDAC differs for each site according to the number and types of instruments installed. Table 1 lists this information for the primary sites. The data rates specified in Table 1 can easily be transmitted through a single voice channel in the satellite.

If single-channel-per-carrier equipment operating in a burst mode is not employed at the earth stations, then the digital data can be multiplexed* onto the existing carrier,

*The digital bit stream is converted to an equivalent analog signal through a modem, and is then used to modulate the RF carrier. Each data rate can be carried over a single voice channel (bandwidth ≈ 4 kHz); however appropriate line conditioners must be employed for the higher rates.

Table 1. Site Description

Location	Number of Arrays		Data (bits)		Total Raw Data[a] (bits)	Total Data Return Rate (bps)
	Long Period	Short Period	Long Period	Short Period		
Iran	9 (3 component)	3	540	1200	1740	2400
Korea	7 (3 component)	19 Vertical	336	6080	6416	4800[b]
NORSAR	22 (3 component)	Selected	1056	480	1536	2400

[a]This does not include header information and other overhead data.

[b]All long-period data and 10 channels of short-period data only for a total of 3536 bps plus overhead.

transmitted through the satellite, and received at the U.S. earth station in Etam, West Virginia. Data from the Korean site can be received at Jamesburg, California. The data can then be demultiplexed and enter the ARPANET through the Terminal Interface Processor (TIP) located closest to each earth station. The data from Korea would enter the ARPANET at Ames Research Center, Mountain View, California, for transmission to SDAC after being received at the earth station at Jamesburg, California. Data from NORSAR could enter the ARPANET at the site where a TIP is located. Otherwise, data entering the U.S. from NORSAR, as well as data from Iran, via the Etam, West Virginia, earth station, would be transmitted to the SDAC via local terrestrial networks.

Three basic system approaches were investigated for returning data via the satellite:

a. use of terrestrial microwave systems from the seismic site to the INTELSAT earth station, and subsequent transmission to the satellite on a standard FM carrier;

b. construction of a nonstandard station* at the seismic site for direct access to the satellite; and

c. possible use of packet-switching technology by extending the ARPANET to foreign countries.

In each case technical and economic factors must be considered, as well as any political matters which may affect the implementation of a particular system approach. It must be recognized that access to the space segment, i.e., the satellite, by means of other than previously approved standard techniques must be

*A nonstandard earth station is one that does not meet the minimum standards set by INTELSAT.

approved by the INTELSAT Board of Governors. In addition, tariffs are determined by the communications entities within each country, and not by COMSAT or INTELSAT. Approval for access to the satellite and tariffs to be charged are determined by the type of service being offered.

The balance of this report is divided into five additional sections. Sections 2, 3, and 4 will describe the requirements for Norway, Iran, and Korea, respectively. They will include discussions on the type of data collected at each site, the present terrestrial facilities available for transmitting the data back to SDAC, and tariffs. Section 5 will discuss SPADE and single-channel-per-carrier (SCPC) operation, along with link calculations, equipment costs, and the modifications that would be required to implement packet switching. The sixth section will contain recommendations and conclusions.

2. NORWAY (NORSAR)

2.1 GENERAL DISCUSSION

Of the two seismic arrays located in Kongsberg and Kjeller, Norwav, only the latter array is of importance to ARPA. Both arrays have long-period (LP) and short-period (SP) seismometer; however, only LP data would be returned from Kongsberg if these data were requested. At present photographic plates from Kongsberg are mailed daily to the Bergen Observatory, where they are developed and examined. Tapes from the recorder are mailed bi-weekly to Bergen and forwarded to NOAA. Data processing is performed by the Data Logger manufactured by Astro Data.

The addition of header information, containing 12 characters at six bits per character, results in a bit rate of 72 bps. This information, together with the seismic data at 48 bps, results in a total bit rate of 120 bps. This data rate can easily be transmitted over existing telephone lines from Kongsberg to Kjeller, where it can be added to the data from NORSAR for transmission to SDAC. As will be shown later, due to the costs involved in implementing a nonstandard earth station, it would be economically more advantageous to transmit the data over terrestrial lines to Kjeller.

At Kjeller the data consist of samples taken from 22 three-component LP instruments once per second using 15-bit words, plus samples taken from a number of SP instruments 10 times per second using 10-bit words. The total data rate from the NORSAR station is 2400 bps, which includes overhead data and spare bits. It should be possible to time-division multiplex the data from Kongsberg with the data stream from NORSAR and transmit it all back to SDAC over the same carrier. The bit rate of 2400 bps can be carried over a single satellite channel.

From NORSAR there is presently a 2400-bps data link to SDAC. Previously, the circuit used Milgo modems and transmitted data from the LP instruments (1056 bps) plus selected SP data. The link has been upgraded to 9600 bps using Codex modems, and has been extended to London. At Kjeller the London circuit will interface with a TIP and a Codex 9600 modem with the multiplex option, enabling the 2400-bps data from the Kjeller station processing system (SPS) to be multiplexed onto the link. Later, it may be upgraded to 50 kbps. The present line to the Tanum earth station meets C.C.I.T.T. specification M.102.

There is a 2400-bps data link from each of the subarrays to Kjeller. On these lines, the error rate is automatically measured every 16 minutes. A line is declared "good" if less than 20 errors are recorded in 16 minutes (a BER of approximately 10^{-5}). If more than 200 errors are recorded, the data are deleted. If between 20 and 200 errors are recorded, the line is considered to be "degraded." The station manager's opinion is that, for the overall link, a BER of 10^{-5}, or perhaps even 10^{-4}, should be acceptable. There is also a 75-bps order wire channel to the subarrays. An order wire channel from NOAA/SDAC is probably unnecessary, but might be helpful later if access to data banks in the United States can be obtained. Header information should be generated directly from the SPS by direct programming into the software.

Communications equipment could be located in the NORSAR building. The modem room contains the Codex modem and five bays of modems to the subarrays. There is also a telephone which can be used in the alternate voice/data mode to SDAC, but it is used only once or twice a month. Space is available for about half of a bay of equipment. The TIP will be located in the adjacent computer room.

Temperature and humidity are controlled for a computer environment. NORSAR has good electronics technicians who could operate and maintain any communications equipment. Commercial power is generally very reliable, with only a few short outages during lightning storms. There is no standby power except power for emergency lighting.

2.2 TERRESTRIAL AND EARTH STATION FACILITIES

Figure 1 is a map showing the locations of Kjeller and Kongsberg, Norway, and the earth station at Tanum, Sweden. Present plans call for a maximum bit rate of 2400 bps to be transmitted from NORSAR back to SDAC over the 9600-bps data link presently established between the Scandinavian earth station at Tanum and the U.S. earth station at Etam, West Virginia, via the Atlantic INTELSAT IV satellite. Access to the data link in Europe is at Kjeller, Lillestroem. On the U.S. side, access is at the ITT gateway station in Washington, D.C.

The only problem involved in implementing the 2400-bps data line from Kjeller would be the lead time required to obtain the modems for the terminals. The line would be in accordance with C.C.I.T.T. Rec. M.102. Line reliability could not be defined by the Norwegian Telecommunications Administration (NTA); however, they believe that it should be good. Based on the small amounts of information which they have obtained on the transmission of 2400-bps data, a BER of 10^{-5} should be achieved.

The data from Kongsberg can be sent to Kjeller over a 100-baud telegraph channel. The NTA has standard telegraph multiplexers. The local loop to the subscriber would consist of normal DC telegraphy, and interfacing with synchronous data should not cause any problems. Since a new line might be required into the mine where the processing equipment is located, a lead time of two or three months might be necessary.

Kongsberg		Kjeller		Tanum	
Lat.	59° 39' N	Lat.	60° N	Lat.	57° 40' N
Long.	9° 36' E	Long.	11° E	Long.	12° E

Figure 1. Map of Kjeller, Kongsberg, and Tanum Earth Stations

2.3 USE OF A NONSTANDARD EARTH STATION AT NORSAR

The NTA has established an informal position that would make the use of a small earth station at NORSAR economically unattractive for the following reasons:

a. The NTA would be responsible for the implementation of the terminal. Ownership and operation of such a terminal would also be subject to the NTA's decision.

b. Leasing charges would be independent of the distance from the customer to the earth station. Therefore the leasing costs would not be reduced by installing a small earth station.

However, should the NTA change its position on the implementation and ownership of a nonstandard earth station at NORSAR, ARPA can realize a number of advantages:

a. maintenance of complete control over the form of data being transmitted, and

b. elimination of possible errors introduced by the terrestrial network.

The implementation should be in the form of preassigned SCPC operation. A more detailed description of SCPC operation is presented in Section 5.

2.4 TARIFFS

Tariffs are established by the NTA for the services rendered, and are independent of the distance between terminal points. Hence, there is a specific rate for the transmission of

data to the satellite from any location within Norway. As a result, the charges would be the same for transmission from the earth station at Tanum, Sweden, and from a nonstandard earth station constructed at NORSAR (Kjeller) or Kongsberg.

The cost of a 2400-bps data circuit between NORSAR and Washington would be as follows:

Kjeller to satellite:	$5325/month
satellite to Washington:	4625/month
TOTAL	$9950/month

The costs of a 100-baud teletype circuit and 2400-bps data circuit from Kongsberg to Kjeller would be

2400-bps data circuit with 75-bps backward channel	$425/year
special quality line (M.102)	$532/year
modem	$ 95/year
initial charge for modem	$495
100-baud teletype	$275/year
initial charge for teleprinter	$112

3. IRAN

3.1 GENERAL DISCUSSION

The Iranian array at Eshtehard will send raw data to the University of Tehran. The bit rate of the raw data is 1740 bps, i.e., nine 2-component LP instruments (540 bps) and three SP instruments (1200 bps). At the University, appropriate header information for use at SDAC is added by the station

processor. This includes synchronization, date and time information, station status and identification, and possibly error detection and correction. The composite bit rate (including overhead) is less than 2400 bps.

There is no initial requirement for either full duplex or half duplex data transmission to Iran, and there has been no definite desire for an order wire circuit. A simplex channel capable of 2400 bps with forward error control (FEC) will be assumed as the minimum requirement. A return channel will be needed if ARQ error control is used, or if time sharing of the satellite channel is feasible.

There are a number of means available for providing the channel for retrieving data from the Iranian array. The following were considered:

a. transmission via existing Iranian earth station
   - FDM/FM/FDMA transmission
   - SCPC transmission (preassigned); and

b. transmission via a small earth station at the University of Tehran.

3.2 TRANSMISSION VIA EXISTING IRANIAN EARTH STATION

3.2.1 <u>Interconnection of the University of Tehran and the Iranian Earth Station</u>

3.2.1.1 Existing Facilities

A standard INTELSAT earth station owned and operated by the Iranian Posts, Telephone, and Telegraph (P.T.T.) is located

approximately 350 km west-southwest of Tehran at Asadabad (see Figure 2). A 1200-channel FDM/FM microwave system (Lenkurt 75A) interconnects the earth station with Tehran. All traffic to the earth station enters the mircowave system through the international maintenance center (IMC) at Sepah Square in Tehran. The microwave link will accommodate voiceband data. At present, there is a shortage of multiplex equipment at Sepah Square; however, the installation of new multiplex equipment should be completed around June 1974. The major problem involved in utilizing the Asadabad earth station is that of obtaining a suitable circuit between the University of Tehran and the IMC at Sepah Square.

The existing local subscriber loops within Tehran are not suitable for voiceband data. This has been verified by a user of a circuit leased for voice and TTY.* This circuit has been subject to frequent high thermal and impulse noise and a poor history of cable outages (90- to 95-percent availability). Although the P.T.T. was questioned concerning the availability of a special quality leased telephone line (C.C.I.T.T. Rec. H.12), no answer has yet been received.

Errors resulting from terrestrial systems generally occur in bursts rather than at random, as in a satellite link. It is possible to employ ARQ error control and specially coded forward error control (FEC), which give some degree of protection against bursts of errors. However, no error correction scheme, ARQ or FEC, could overcome the reliability problem of the local subscriber loops. Hence, the use of the existing local subscriber loops is not advised.

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*The U.S. Army STRATCOM Agency has a voice plus TTY circuit from Tehran via Asadabad and Etam to Ft. Dietrich, Maryland.

Figure 2. Map of Northwestern Iran Showing Tehran, Asadabad, and Eshtehard

3.2.1.2 Low-Capacity UHF Microwave Link

Low-capacity microwave equipment available from several manufacturers at UHF (400 MHz or 2 GHz) will economically accommodate as few as six voice or data channels. Since the path length to Sepah Square from the University is only five miles, it is possible to implement a 1-hop system with moderate tower heights (100 ft). A typical system at 2 GHz would have the parameters listed in Table 2.

Table 2. Parameters of a Typical 1-Hop, Low-Capacity UHF Microwave Link

Frequency	2 GHz
Transmit Power	2 W
IF Bandwidth	200 kHz
Noise Figure at Receiver	8 dB
3-ft Parabolic Antenna Gain	23 dB

Preliminary system calculations show the feasibility of such a link; a detailed frequency coordination and path survey would be performed by the equipment supplier or the P.T.T. The power budget for a 5-mile path at 2 GHz is shown in Table 3.

Table 3. Power Budget for a Typical 1-Hop, Low-Capacity UHF Microwave Link

Transmit Power	+33 dBm
Waveguide or Helix Loss	-3 dB
Transmit Antenna Gain	+23 dB
Path Loss at 2 GHz	-117 dB
Receive Antenna Gain	+23 dB
Waveguide or Helix Loss	-3 dB
Implementation Margin	-3 dB
Unfaded Carrier Power	-47 dBm

Noise figures of 8 dB are common in microwave systems. If an antenna temperature of 290°K is assumed, the noise due to the path at the receiver can be calculated as follows:

$$N = kTBF$$

where

k = Boltzmann's constant = -198.7 dBm/°K

T = reference noise temperature = 290°K = 24.6 dB-°K

F = noise figure = 8 dB

B = noise bandwidth = 200 kHz = 53 dB-Hz

Hence, N = -113 dBm.

For a threshold carrier-to-noise ratio of 10 dB, the received carrier level at threshold is -103 dBm. This allows a more than adequate fade margin of 56 dB. The only noise attributable to the microwave system will then be the intrinsic noise of the equipment. The estimated costs of an installed microwave system are shown in Table 4. Suitable prime power has been assumed.

Table 4. Estimated Costs of Installed Microwave System

Transmitters/Receivers	$10,000
Multiplexers	3,000
Towers	5,000
Antennas	600
Helix	400
Local Order Wire	1,000
Installation	5,000
Contingency	5,000
TOTAL	$35,000

The voiceband data circuit would be frequency-division multiplexed at Sepah Square onto the existing 1200-channel microwave system to Asadabad. It should be noted that there are precedents for user-owned and -operated microwave facilities in Iran.

3.2.2 FDM/FM Transmission between Asadabad and Etam

At Asadabad, the circuit could be frequency-division multiplexed onto the multidestination carrier which is received at Etam. The transmission technique currently utilized for most voiceband data in the INTELSAT network employs FM carriers. It is likely that only full duplex service will be offered.

Voiceband bit-error rates averaging 1×10^{-7} have been measured over double-hop loops (earth station A to earth station B and return) on operational carriers. Envelope delay measurements have shown that specifications for Bell System C-2 conditioned lines and/or C.C.I.T.T. Rec. M.102 can be met between earth stations. Impulse noise is typically less than 6 counts per 15 minutes for levels exceeding -21 dBm0, or one half of the allowable counts recommended by C.C.I.T.T. Rec. V.55. Phase jitter is typically less than 1.0° peak-to-peak and less than 0.3° rms. This performance is excellent according to terrestrial standards. The transmission parameters for a 5-MHz, 60-channel carrier are shown in Table 5. This is the carrier size being transmitted from Asadabad to Etam, West Virginia. It is presently 80-percent loaded (48 channels), with a predicted loading of 56 channels by the end of 1974.

Table 5. Existing 60-Channel FDM/FM Multidestination Carrier Transmitted by Asadabad

Channel Capacity	60 channels
Satellite Bandwidth	5.0 MHz
Occupied Bandwidth	4.0 MHz
rms Multichannel Deviation	546 kHz
Carrier-to-Noise Ratio	12.7 dB
Approximate Earth Station e.i.r.p.	77.8 dBW
Apprioriate Satellite e.i.r.p.	8.9 dBW

3.2.3 SCPC Transmission

SPADE equipment will be installed in the Iranian earth station by the third quarter of 1974. With no modifications, the existing SPADE terminal can be utilized for voiceband data on a preassignment basis. SPADE and SCPC differ primarily in the method used for frequency assignment; i.e., the former is demand assigned and the latter preassigned. The transmission characteristics of both modes of operation are fully compatible.

To preassign a SPADE channel at Etam and Asadabad, one of the channels presently set aside for preassignment operation will be used. The preassigned frequency will be manually dialed into the frequency synthesizers. Preassigned SPADE provides a full duplex circuit.

3.3 USE OF A SMALL EARTH STATION AT UNIVERSITY OF TEHRAN

There are several advantages of locating a small earth station at the University of Tehran:

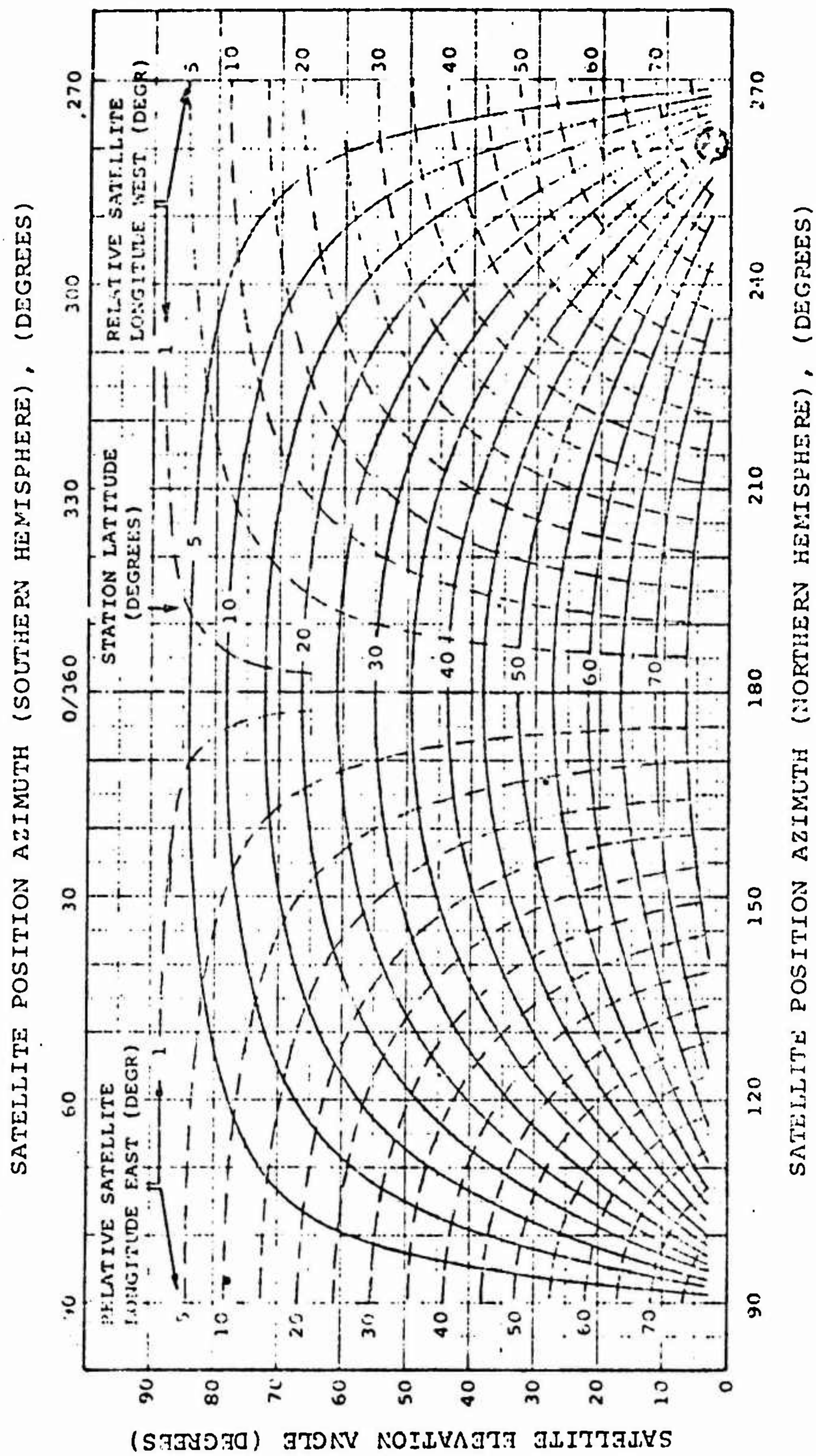
a. elimination of the interconnection to the Asadabad earth station with its attendant costs and especially the necessity of installing a UHF microwave link to avoid the local subscriber loops, and

b. elimination of potential political and maintenance problems involved in locating nonstandard equipment at the Asadabad earth station.

Several locations on the University complex are suitable for a small earth station installation. To the north, northwest, and northeast, high mountains approximately 30 miles away have an elevation angle of about 9° at the crest. Due east the local hills crest at an elevation angle of about 5°. In the direction of the satellite, the elevation angle to the top of nearby hills is about 0°. The information necessary to perform frequency coordination for siting a small earth station is classified; actual coordination would be accomplished by the Iranian Ministry of Posts, Telephone, and Telegraph.

At Tehran the Atlantic primary INTELSAT IV satellite in its normal position appears at 3° elevation on an azimuth of 260° (see Figure 3). Satellite drift could cause the elevation angle to be as low as 2°. Available experimental evidence obtained by using an 85-ft-diameter antenna with a beamwidth of approximately 0.20°* indicates that carrier power fluctuations of up to 3 dB occur at elevation angles 3° above the local horizon. These fluctuations are primarily due to multipath effects. The large-aperture antenna used for the measurements was able to discriminate against reflections outside its beamwidth. A 16-ft antenna (1° beamwidth) at a small earth station would experience much greater variations.

*The reference data were obtained at the Goonhilly Downs antenna in the U.K. operating on the relay satellite at 4080 MHz.



SATELLITE 335° 30' E
0° 0' N

TEHRAN 50°E
36°N

Figure 3. Position Arcs of Geostationary Satellites

Since a low elevation angle path extends through more of the atmosphere, it would be subject to greater precipitation attenuation. Occasional heavy rain occurs in Iran; however, the rainfall statistics are not known. In arid areas rainfall rates of 3 mm/hr can occur during up to 0.1 percent of the time. The attenuation at 6 GHz is less than 3 dB. In addition, International Radio Regulation 470L prohibits the use of earth stations with elevation angles less than 3°, and as stated in the previous paragraph, satellite drift may cause the elevation angle to be less than 3°. For these reasons, the use of a small antenna at the University is not recommended.

To obtain a 5° elevation angle, which has been proven reliable, the antenna would have to be approximately 350 km west of Tehran. This would require a multihop (>5) microwave system whose operation and maintenance would be costly for one channel. Therefore this alternative is not recommended.

3.4 TARIFFS FOR TRANSMISSION VIA ASADABAD

The Iranian P.T.T. Administration presently separates space segment and terrestrial tariffs. The total monthly leasing charges for a full duplex voice circuit between Tehran and Washington are

Tehran to satellite:	$10,000
satellite to Washington:	4,625
	$14,625

The UHF microwave system described in Subsection 3.2.1.2 and data modems could possibly be furnished by the user. The equipment costs would be as follows:

modem, 2 ea:	$ 5,000
UHF microwave Link:	35,000
	$40,000

4. KOREA

4.1 GENERAL DISCUSSION

The Korean array at Camp Long processes the raw seismic data collected by seven LP instruments and 19 SP instruments. Sixteen-bit encoding is used on the data, resulting in approximately 6400 bits of data. However, data from only 10 of the 19 SP instruments are to be returned to SDAC along with all LP data. As a result of this limited data requirement, a total of 3536 bps are to be returned. With the addition of header information, a total of 4800 bps will be transmitted back to SDAC via the satellite link.

There is no requirement for a full duplex circuit to Korea, nor is there a need for an order wire to the seismological station. A simplex channel capable of 4800 bps with FEC will be assumed to meet the data transmission speed requirements. Similar to the Iranian configuration, a return channel will be required if ARQ error control is used, or if time sharing of the satellite channel is desirable.

Three alternate approaches for transmitting the data from Camp Long to the Pacific INTELSAT satellite were investigated:

a. use of a local commercial terrestrial microwave system for Wonju (just outside of Camp Long) to Kum San via Seoul (see Figure 4);

b. use of a military terrestrial system from Camp Long to Yongsan (just outside of Seoul), then into Seoul, and down to Kum San via a commercial terrestrial microwave system; and

c. installation of a nonstandard earth station at Camp Long for direct access to the Pacific satellite.

Of these options, installation of a nonstandard earth station at Camp Long would not be authorized by the Korean Ministry of Communication (MOC). The use of the military microwave links was not recommended due to the poor quality of the system. STRATCOM personnel in Korea stated that new radio equipment (AN/FRC-109) was to be installed between Comp Long and Yongsan during the first quarter of 1974; however, neither the installation nor the quality of service the link can maintain has been confirmed. The AN/FRC-109 radio equipment is manufactured by Lenkurt, Inc.

The use of the local terrestrial system would require the installation of a link between Camp Long and the IMC in Wonju. The line-of-sight distance is approximately 3 miles; however, because the terrain is very hilly between Camp Long and Wonju, it might be necessary to include a passive reflector or some other type of repeater between the terminals. If this is necessary and land must be purchased for this purpose, a change in the Status of Forces Agreement (SOFA) might have to be initiated. The Korean MOC would want ARPA to install and maintain the

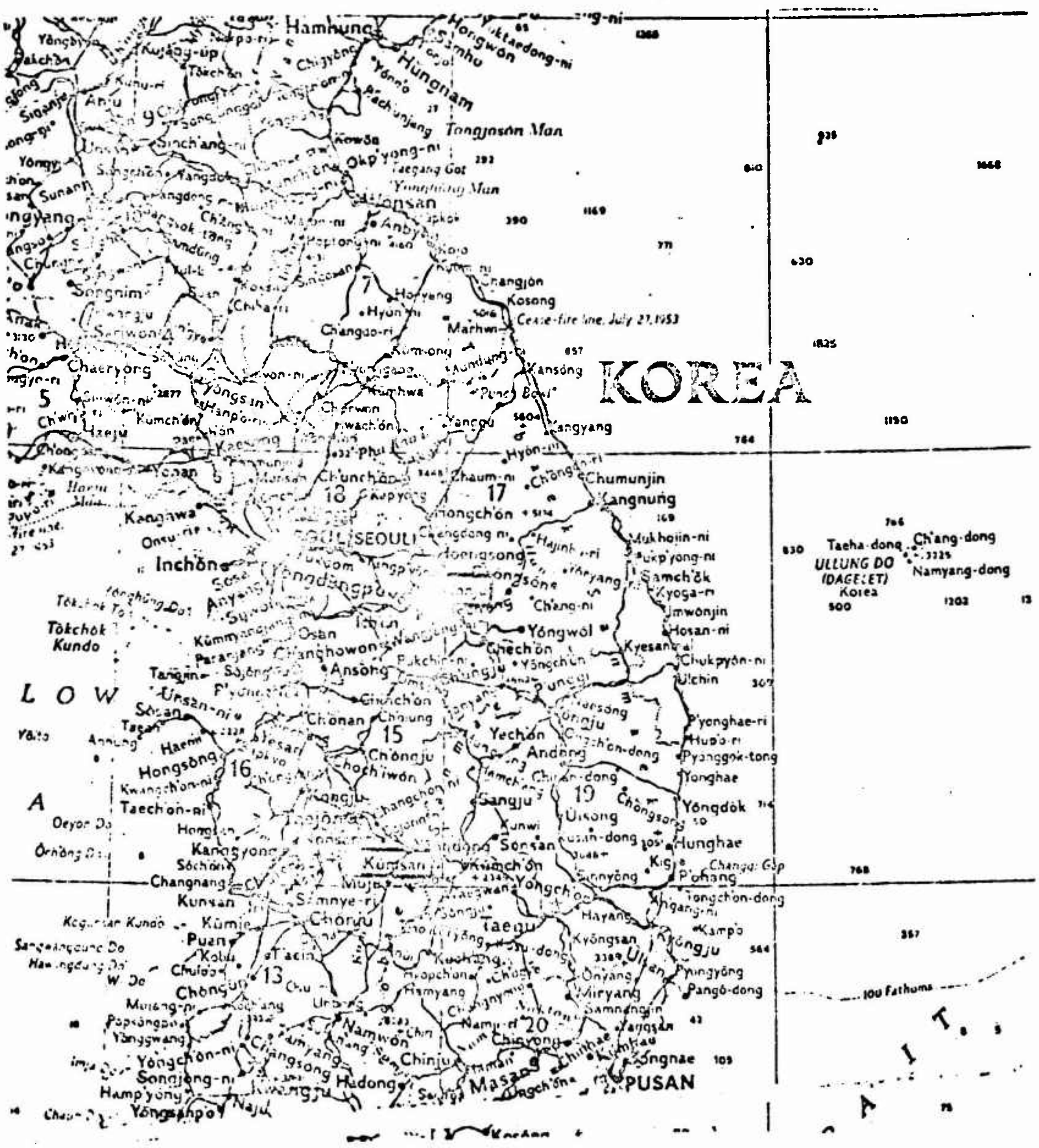


Figure 4. Map of Korea Showing Wonju, Seoul, and Kum San

microwave link between Camp Long and the IMC in Wonju. Site clearance, frequency coordination, and path survey would have to be coordinated with the MOC, who would maintain all equipment installed by them.

If a line-of-sight path were installed at an operating frequency of 2 GHz, then the link parameters described in Subsection 3.2.1.2 for the Iranian link would also be used for the Korean link. However, since the path distance is 3 miles rather than 5 miles, the path loss would be 5 dB less. Therefore, if a 0.5-W transmitter were used instead of the 2-W transmitter assumed for the Iranian link, the net change would be -1 dB. The unfaded carrier power would be -48 dBm, which is still well above the noise threshold of -113 dBm. The cost of installing the system would be essentially the same as that of the Iranian system, i.e., $35,000.

In 1971 tests were performed by RCA GLOBECOM in conjunction with the U.S. earth station at Paumalu to determine the quality of the terrestrial microwave network from the Kum San earth station to Seoul. A 2400-bps data channel was transmitted from Paumalu via the Pacific Ocean satellite down to Kum San, and then via the terrestrial network to Seoul. The test results given in Table 6 are within the specifications given in C.C.I.T.T. Rec. H.12, Subparagraph B,* "Special Quality Telephone-Type Circuits." With proper equalization in the modems, there should be no problem in transmitting 4800-bps data over the existing Korean terrestrial network.

*The Series H recommendations are for lines used for the transmission of signals other than telephone signals, such as data, facsimile, and telegraph.

Table 6. Circuit Parameter Test Report

Name of Test	Measurement
1. Frequency Response	
300 to 2000 Hz	-0.7 to +0.6
500 to 2800 Hz	-0.6 to +0.5
2. Envelope Delay	
500 to 2800 Hz	140 μsec
600 to 2600 Hz	80 μsec
1000 to 2500 Hz	75 μsec
3. Net Loss Variation	-0.1 dB
4. Frequency Translation	-1.9 Hz
5. Idle Channel Noise	35 dBRNCO
6. Impulse Noise	3 dB at 72 dBRNCO
7. Phase Jitter	<5°
8. Harmonic Distortion	
700	N/A
1400	N/A
2100	N/A
2800	N/A
9. Single Tone Interference	N/A
10. Terminal Impedance	
In	630 Ω
Out	550 Ω
11. Longitudinal Balance	
In	40 dB
Out	40 dB

4.2 TARIFFS

The cost of leasing a single voice channel from the IMC in Seoul to the satellite is $14,000 per month. An additional

$367.50 would be added to this cost for the link from Wonju to Seoul.

On the U.S. side, the tariff would be $2500 per month for reception at Jamesburg, California. The terrestrial charges for transmitting the data from Jamesburg to Mountain View, California, where an ARPA TIP is located, would be approximately $250 per month.

5. TRANSMISSION TECHNIQUES

5.1 FDM/FM/FDMA

The present mode of operation within the INTELSAT system employs standard FM carriers whose specific bandwidths depend upon the number of channels being transmitted by the earth station. Low-speed data equal to or less than 9600 bps can be transmitted through a voice channel on the carrier. The data bit stream is converted to an equivalent analog signal at the channel baseband frequency and multiplexed onto the carrier as an additional channel (see Figure 5).

The digital data stream is applied to the modem, which converts the bit stream to an equivalent analog signal with a channel passband of 3.1 kHz. This signal can then be treated as an equivalent baseband voice type of signal which can be used to modulate a channel of the FM carrier. The carrier is transmitted via a microwave link to an IMC, where it is received, combined with other audio channels, and transmitted to the INTELSAT earth station. At the earth station it is applied to the standard FM carrier through the earth station processing equipment and transmitted to the satellite.

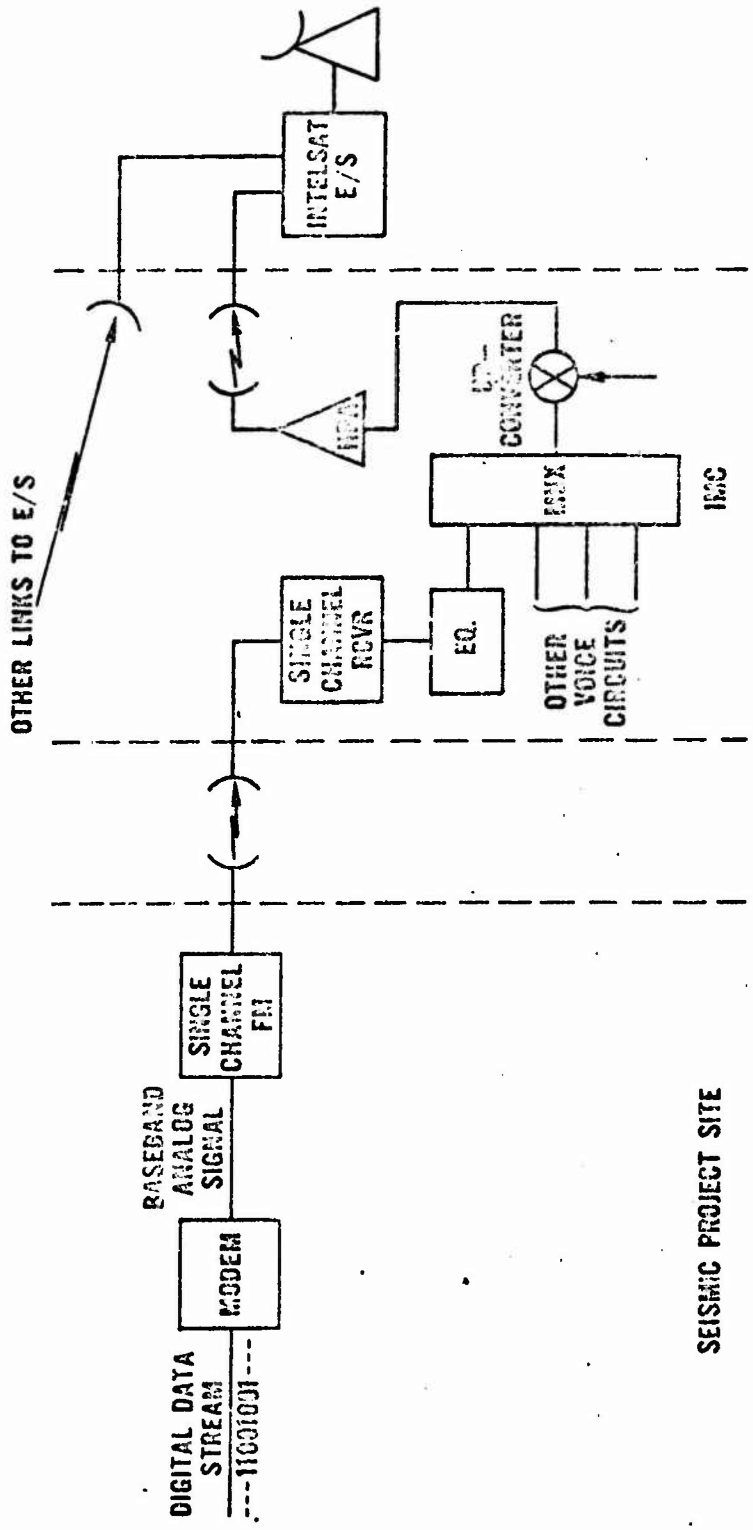


Figure 5. Digital Data Transmission via FM Carrier

Upon reception at the U.S. earth station, the channel is demultiplexed and sent as a baseband signal to SLAC if it is received on the East Coast, or to Ames Research Center if it is received on the West Coast. At either facility, the signal is demodulated and reconverted to the original data stream. When the signal is being transmitted at baseband, proper equalization and conditioning of the lines must be maintained. (This depends upon the type of modem being employed, since some self-equalizing modems require no special line conditioning.)

5.2 SINGLE CHANNEL PER CARRIER

Earth stations equipped with SPADE or SCPC require no modifications for transmitting voiceband data on a preassigned basis. SPADE and SCPC differ primarily in the method used for frequency assignment; i.e., the former are demand assigned and the latter preassigned. The transmission characteristics of both modes of operation are fully compatible (see Figure 6). The data are fed directly to a PCM encoder which uses 7-bit encoding and A-law companding. The sampling rate is at 8000 Hz; therefore, the output of the encoder is 56 kbps. Although more work must be done in this area, laboratory tests have shown that little degradation is introduced by resampling the input data using the PCM encoder for bit rates up to 4800 bps.

Normally, the voice detector is used to ensure that the carrier is transmitted only in the presence of voice to conserve satellite power. In a continuous data mode, the voice detector is disabled. When the carrier is turned on, a preamble consisting of 120 bits of carrier and bit timing recovery information is generated in the transmit synchronizer. This allows the demodulator at the distant end to coherently receive the carrier and recover a bit timing clock. The preamble is followed by a unique

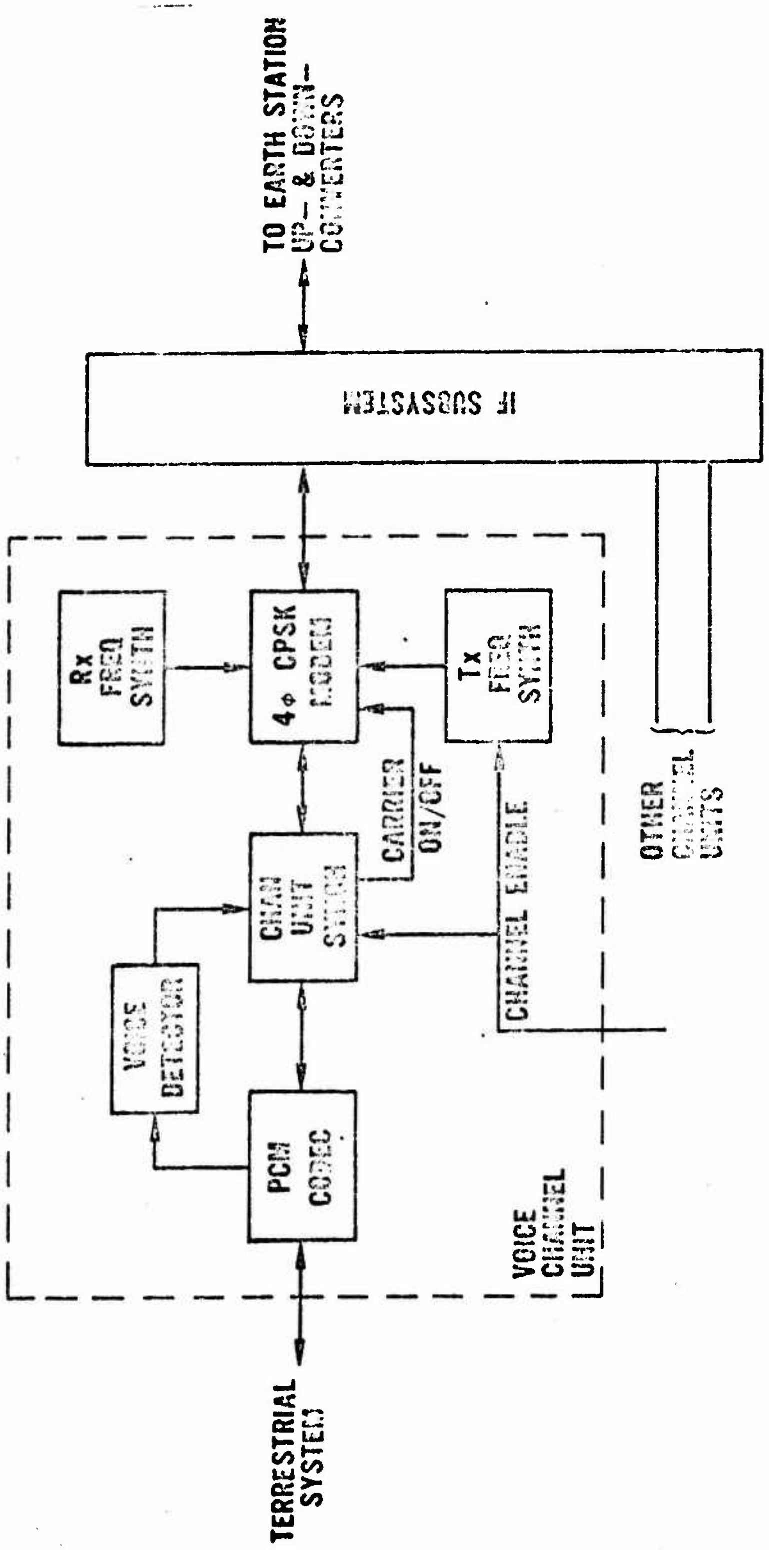


Figure 6. Voice Channel Unit

word which enables resolution of phase ambiguity and frame synchronization at the receiving end. After acquisition, unique words are added periodically at rate 7/8 to maintain synchronization and ambiguity resolution. The input to the 4-phase PSK modulator is therefore 64 kbps. The frequency synthesizer translates the modulator frequency to the earth station intermediate frequency.

To preassign a SPADE channel, the preassigned frequency is dialed into the frequency synthesizer and set on the manual mode. Preassigned SPADE provides a full duplex circuit. The transmission parameters are listed in Table 7.

Table 7. Satellite Link SCPC and Transmission Parameters

Parameter	Requirement
Audio Channel Input Bandwidth	300-3400 Hz
Encoding	7-bit PCM A = 87.6 companding law
Modulation, Ambiguity Resolution	4-phase coherent PSK, unique words
Channel Spacing	45 kHz ± 50 Hz
Bandwidth Unit	45 kHz
IF Noise Bandwidth	38 kHz
Required C/T per Channel at Threshold	-169.8 dBW/°K
C/T per Channel at Nominal Operating Point	-167.3 dBW/°K
Threshold C/N in IF Bandwidth	13 dB
Threshold Bit-Error Rate	10^{-4}
Bit-Error Rate at Operating C/N	10^{-7}
Maximum Earth Station e.i.r.p. at 10° Elevation Angle	62.5 dBW
Nominal Satellite e.i.r.p. at Beam Edge	-6.5 dBW
Bit Rate on Satellite Channel	64 kbps

5.3 USE OF A DATA CHANNEL UNIT

The SCPC terminal can be equipped with a data channel unit to accept 50-kbps data and transmit it over a satellite channel on a preassigned frequency. This would be identical to the 4-phase CPSK transmission used on the Hawaii extension of the ARPA network (see Figure 7). The incoming 50-kbps serial bit stream enters the data interface unit. This unit meets the standard C C.I.T.T. V.35 data interface used in Europe or the standard WE 303 interface used in North America. The data interface unit also phase locks the channel unit clock to the incoming data bit stream on the transmit side (if required) and provides clock timing and phasing on the receive side.

After the data interface unit, the 50-kbps data enter a rate 3/4 convolutional FEC encoder. The encoded bit rate is then 66.67 kbps, which is sufficiently close to the modem operating bit rate of 64 kbps that only minor internal adjustments to the bit timing recovery circuit of the receive modem are required. Rate 3/4 threshold decoding is performed after demodulation. As a result of coding, the bit-error rate is enhanced from $P_{BE} = 1 \times 10^{-4}$ to $P_{BE} = 1 \times 10^{-7}$. Resolution of phase ambiguity, a process which may require up to 0.5 sec. from the beginning of the carrier burst, is performed in the threshold decoder. Since the mode of operation is continuous, carrier acquisition can be a random process (up to 0.5 sec.), and carrier and bit timing recovery information is not required. The transmission parameters are described in Table 8.

For 50-kbps service, the SPADE equipment on the transmit end would need modifications. Specifically, the wiring of a channel unit shelf would have to be modified and provisions made for data channel units. At the receive end, two channel units would be needed. The estimated costs of hardware are detailed in Table 9.

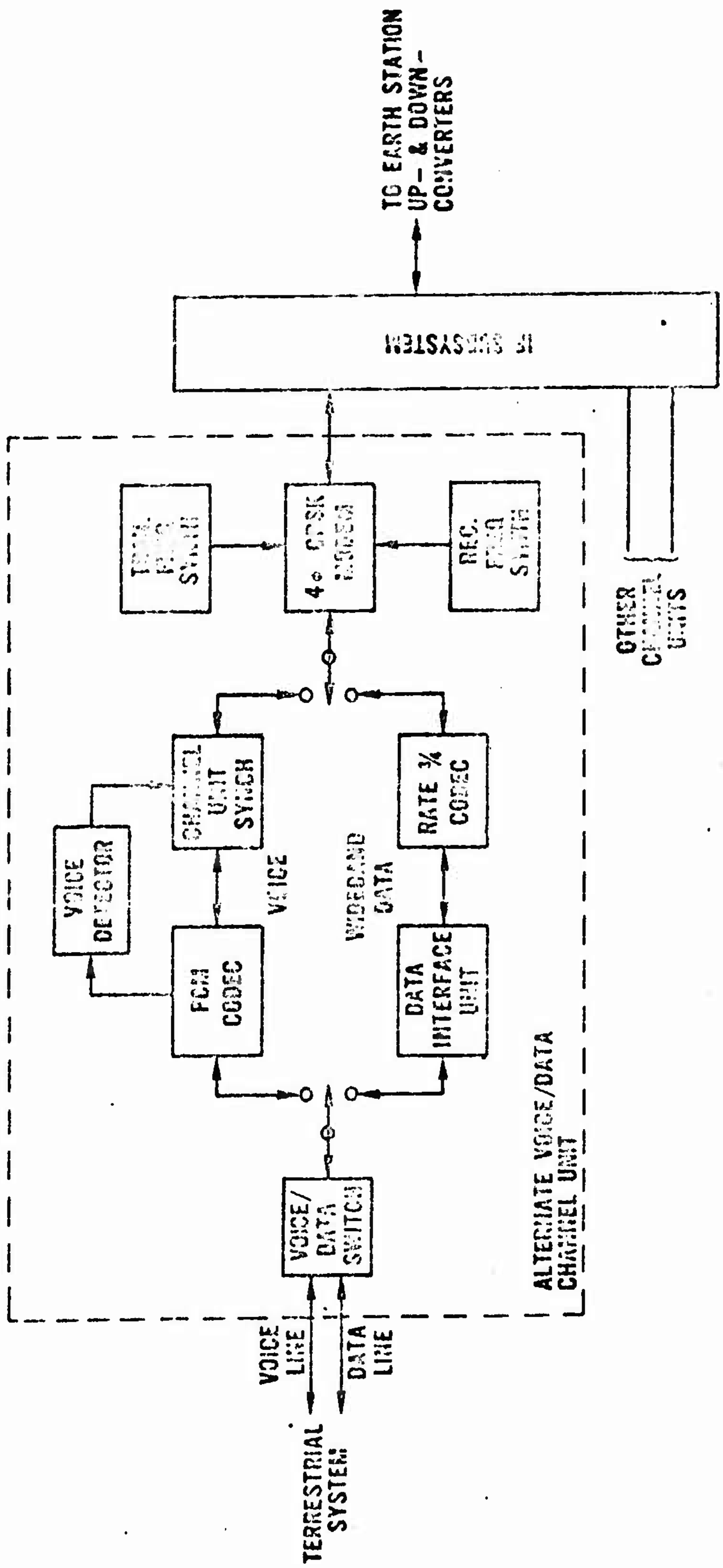


Figure 7. Alternate/Data Channel Unit

Table 8. SCPC Characteristics and Transmission Parameters for 50-kbps Data

Parameter	Requirement
Input Bit Rate	50 kbps
Encoding	rate 3/4 convolutional encoding, threshold decoding
Modulation, Ambiguity Resolution	4-phase coherent PSK, within rate 3/4 codec
Channel Spacing	45 kHz ± 50 Hz
Bandwidth Unit	45 kHz
IF Noise Bandwidth	38 kHz
Required C/T per Channel at Threshold	-169.8 dBW/°K
C/T per Channel at Nominal Operating Point	-167.3 dBW/°K
Threshold C/N in IF Bandwidth	13 dB
Threshold Bit-Error Rate	10^{-7}
Bit-Error Rate at Operating C/N	10^{-9}
Maximum Earth Station e.i.r.p. at 10° Elevation Angle	62.5 dBW
Nominal Satellite e.i.r.p. at Beam Edge	-6.5 dBW
Bit Rate on Satellite Channel	66.67 kbps

Table 9. Hardware Costs for 50-kbps Service

Transmit	
Data Channel Unit, 2 ea	$16,000
Shelf Modification	7,500
Data Error Test Set, 1 ea	4,000
	$27,500
Receive	
Data Channel Unit, 2 ea	$16,000

5.4 ERROR CORRECTION

End-to-end error correction will be provided by the station processing equipment. Since seismic data are inherently redundant (a low-frequency analog signal is sampled at a high rate), it is felt that bit-error rates of 1×10^{-4} should be acceptable. The following brief comments concern different error correction techniques which are being considered.

In the basic ARQ system, a block of data is transmitted. The sending station then waits for an acknowledgment or a request for transmission. The waiting period in satellite links includes two round trip propagation times to the satellite, or as much as 550 msec. This long round trip delay results in an unacceptable loss of throughput efficiency at voiceband data rates and above.

A "go-back-n" ARQ system is more suitable for satellite applications. In this scheme, a request for retransmission occurs only upon receipt of an error. Coding is used to detect the presence of an error. A request for retransmission starting n blocks back, where n is a fixed number of block lengths (usually three or four), is then sent on a return channel. The go-back-n error correcting system is especially suitable for handling burst errors because retransmission is requested regardless of the number of errors in the block. Terrestrial system errors tend to be "bursty," while satellite link errors tend to be randomly distributed. The disadvantage of this system is that a return channel must be utilized and buffers must be provided to store data for retransmission.

Forward acting error correction uses coding to detect and correct errors. No return channel is required. The disadvantage of FEC is that it can correct only a limited number of errors in a given number of consecutive bits.

5.5 TIME-SHARED TRANSMISSION

Time sharing of a single channel in the satellite by two or more stations may be an alternate method of reducing costs. However, at the present time this type of service is not offered by INTELSAT.

Basically, time sharing of the satellite channel is accomplished by setting specific time slots, relative to a master sync-timing pulse, for each station to transmit its burst of data. In general, each station transmits sequentially in a burst following each timing pulse, with some guard time allowed between station bursts. Since a SPADE channel is used in the satellite, the data rate from each station is 64 kbps. The seismic data entering the station are at a relatively slow speed (up to 4800 bps).

To transmit in bursts at 64 kbps, some means of storing the data must be provided. The size of the buffer determines the frequency of transmission, since, e.g., buffers with 56 kb* of storage must transmit half as often as buffers with 28 kb of storage. Smaller buffers require tighter synchronization control and shorter transmission bursts, with each burst preceded by a synchronization preamble. This in turn results in lower overall channel utilization and efficiency.

The data channel units are designed to operate in a continuous mode. Significant modifications are required for non-continuous operation. A time-shared satellite channel would require sequential access to the channel by several earth stations. Hence, the carrier would have to be modified to provide the SCPC channel unit with the added capability to turn the carrier power

*56 kb, when coded at rate 7/8, or 48 kb, when coded at rate 3/4, will result in a transmission data rate of 64 kbps.

on and off by external means. With this modification, an earth station user would turn the carrier power on, transmit his burst of data, and then turn the carrier off.

A second problem produced by allowing sequential access to a single channel is that receiver synchronization must proceed rapidly. With the existing rate 3/4 codec, synchronization is a random process requiring up to 0.5 sec. To speed up the acquisition process at the receiver, it is suggested that the synchronization scheme used in the present SCPC channel should be replaced by a scheme similar to that used for the voice mode of the SPADE system. With this synchronization system, a 32-bit unique word is transmitted at the beginning of each data burst. This synchronization word is used to resolve the ambiguity produced by the 4-phase PSK demodulator. Following initial acquisition and ambiguity resolution, subsequent ambiguity resolution is performed by the rate 3/4 codec, as in the present SCPC equipment. Hence, initial synchronization and resolution of ambiguity are performed by the sync word, and subsequent ambiguity resolution is performed by the rate 3/4 codec.

Another recommended modification would permit the 4-phase PSK demodulator to acquire the carrier more quickly. This implies the use of a switching loop to switch the carrier to a narrow loop bandwidth following acquisition.

The present demodulator provides an indication of both carrier and bit timing recovery to the data error codec within 1.7 msec after the start of preamble reception. This feature can be retained and the "carrier acquisition" signal given to the user.

This data channel unit can be modified to operate in conjunction with a satellite interface message processor (SIMP). After discussion with BBN, it has been mutually agreed that the

SIMP should be located at the earth station for technical simplicity. It should be emphasized, however, that installation of a SIMP at an earth station and extensive modifications to the equipment are the options of the earth station owner.

It would seem that a 9- to 12-month contract would be sufficient for a company that is doing work in this area to develop the necessary equipment for a modified channel unit. A development contract should not cost over $30,000 and production versions of the channel units with these modifications would probably sell for 10 to 20 percent more than presently existing SCPC hardware ($9,000–$12,000).

5.6 PACKET SWITCHING

The extension of the ARPANET to countries outside the U.S. is being studied by ARPA with the intent of implementing packet-switching techniques for transmission through the INTELSAT satellites over the Atlantic and Pacific Ocean regions. At the present time, packet switching is in an experimental state; hopefully it will become operational over the satellite link within the next two years.

Implementation of packet switching would require the earth station owner to obtain the SPADE or SCPC equipment described in the preceding section and the satellite interface message processor (SIMP). Some modifications to the SPADE equipment would also be necessary to accommodate the packet-switching mode.

Since this mode of data transmission is still an experimental technique, any recommendations concerning the technical and economic feasibility must be deferred until operational experience is obtained through experimentation.

5.7 OTHER DATA SERVICE

COMSAT will soon make available a new data service employing advanced digital techniques which can be transmitted via satellite at bit rates of 2400, 4800, and 9600 bps. The new service, called DIGISAT, employs equipment developed by COMSAT Laboratories and others, and has been tested between the U.S. mainland and the Hawaiian earth stations.

The service is provided by time-division multiplexing a number of data bit streams at various bit rates onto a single data channel for transmission through a SPADE channel in the satellite. The channel can accommodate up to 56 kpbs of data. (The link between Paumalu and Jamesburg was tested at 48 kbps.) Once a tariff has been established for this service and it is approved by INTELSAT, it may be an attractive alternative for transmitting seismic data to SDAC.

6. CONCLUSIONS AND RECOMMENDATIONS

With the installation of a minimum amount of equipment, it should be possible to start transmitting seismic data from the various site locations back to SDAC via INTELSAT satellites. In those locations where additional microwave links must be installed from the seismic sites to a switching center (IMC), only a single data channel is necessary. This channel should have a voice bandwidth of 4 kHz and proper conditioning according to C.C.I.T.T. Rec. H.12 (equivalent to Bell System C-2 or Military D-2 conditioning). The same line conditioning would have to be imposed on the trunk line going from the IMC to the INTELSAT earth station.

Since packet switching is still in the experimental stage, it is not recommended for initial transmission of the seismic data back to SDAC. However, to gain experience in the use of packet switching for the transmission of seismic data, it would be advantageous to include seismic data transmission in the experiments to be performed between the U.S. and U.K. The same terrestrial systems that would have to be installed for transmitting seismic data via the FM carrier through the satellite would also be used for transmitting data via packet-switching techniques. The only difference in equipment is at the earth station, where SIMP and SCPC equipment would have to be installed for packet switching.

Tariffs are determined by the earth station owners. Since the use of packet switching is new to the system, no charging rate has been set. INTELSAT has set a rate for multidestination half duplex (MDHD) service for use of the space segment. This would be incorporated into the earth station tariffs for providing the service.